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Mineral localities on the Mendip Hills, Somerset.

By Arthur W. G. Kingsbury.

[Read March 7, 1940.]

ALTHOUGH the Mendip Hills, as a district, have from time to time received the attention of geologists, details of the mineral occurrences are, on the whole, remarkably scarce. Mining was formerly carried on on the Hills for many centuries, but mineralogy as a science had not been sufficiently developed at the time when the mines were most active, and little interest was taken in the minerals other than those suitable or required for commercial and industrial purposes. Even in later years, when, in the course of treating old refuse and tailings left by earlier miners and of various attempts to resuscitate the mining industry, much material must have been available for examination, little attention seems to have been paid to it, or to the numerous quarries that were opened in the Carboniferous Limestone.

Mention of a few mineral species has been made by writers from time to time, but up to the beginning of last century, by which time practically all work at the mines had ceased, the majority of accounts give little detail and were still concerned more with the commercial aspect. Much interesting information about the old mines has been extracted from old records and put together by J. W. Gough in his book 'The mines of Mendip',[1] but apart from a few general remarks on the minerals, he is more interested in, and treats, the subject from an historical point of view.

The earliest descriptions, from the mineralogical aspect, that are of value, are those recorded by John Woodward (1665–1728) in his 'Catalogue of English fossils', published in 1728–9, in which he describes, among others, a number of mineral specimens obtained by him from

[1] J. W. Gough, Oxford (Clarendon Press), 1930. [M.A. 4–309.]

Mendip. These specimens have fortunately been preserved and are now at Cambridge.

After Woodward, no account of the minerals of this district would be complete without mentioning Spencer George Perceval (1838–1922) who was an ardent collector and greatly interested in the Mendips. Many of his specimens have been preserved, and among them are a number of good specimens from the district, including some of the best-known examples of mendipite and other rare minerals from one of the most interesting localities in the area, Higher Pitts farm, near Priddy.

Apart from these, the only other full accounts are two papers by Dr. L. J. Spencer, 'Leadhillite in ancient lead slags from the Mendip Hills',[1] in 1899, and 'New lead-copper minerals from the Mendip Hills (Somerset)',[2] in 1923. This latter paper deals chiefly with Higher Pitts farm, and describes in detail a number of new and rare species occurring there.

It has been said of the Mendips that, so far as minerals are concerned, this is a district of samples; unfortunately this is only too true, as the small extent of many of the mineral occurrences and the small size of specimens that can be collected has shown, but the number of species to be found is, even at the present time, considerable. Among these species are several rare minerals, and from the occurrence of these and other varieties, the district is of some interest from a topographical point of view.

The majority of the old workings are now very overgrown, with mounds of barren debris left from more recent treatment; and many have been obliterated by building and afforestation. For these reasons, much of the ground is difficult to examine without a great deal of time and energy being expended, and some of the old localities can no longer be traced.

During the last six years, the writer,[3] in continuation and supplementation of the investigations already carried out by Dr. Spencer, has examined some of the localities formerly and more recently described, as well as a very large number of old workings and active and disused quarries. This examination has covered an area nearly 30 miles long, from Uphill on the west to Frome on the east, and 12 miles wide, from

[1] L. J. Spencer, Rep. Brit. Assoc. Adv. Sci., 1899, for 1898 (Bristol), p. 875; Geol. Mag. London, 1899, pp. 71–72.

[2] L. J. Spencer, Min. Mag., 1923, vol. 20, pp. 67–92.

[3] A. W. G. Kingsbury, Notes on some recent finds of minerals on the Mendip Hills. Proc. Somersetshire Archaeol. Nat. Hist. Soc., 1935, vol. 80 (for 1934), pp. 51–56. [M.A. 6-355.]

the level of Chew Stoke on the north to Shepton Mallet on the south. Much of this area contains little or no mineral occurrences worthy of note, and the majority of the localities to be mentioned later are found in the central part.

A number of additional species, not previously recorded from the district, have been discovered, but only in small amounts: these comprise chalcosine, chalcopyrite, chrysocolla, cuprite, melaconite, covelline, rhodochrosite, fluorite, epidote, and laumontite. Further specimens of some of the rarer minerals already described from the district have also been found, and one of the old localities for pyromorphite from which Woodward obtained specimens, mentioned by him in his catalogue, has been re-located, after having been apparently lost sight of since his death.

A certain amount of time and attention has been given to examination of the material still available at Higher Pitts farm, by reason of the presence there of the interesting minerals described by Dr. Spencer. Several of these, namely crednerite ($CuO.Mn_2O_3$), mendipite ($2PbO.PbCl_2$), chloroxiphite ($2PbO.Pb(OH)_2.CuCl_2$), diaboleite ($2Pb(OH)_2.CuCl_2$), hydrocerussite ($2PbCO_3.Pb(OH)_2$), and wulfenite ($PbMoO_4$) are rare as British species. In view of this, particularly in the case of wulfenite, of which only three minute examples had been previously found, careful search for further specimens was made. This has resulted in a number of good specimens of all these minerals being collected, and in the case of wulfenite much larger and more numerous than those hitherto found. Perhaps the most interesting find during the period of investigation of the district was a very fine rough crystal of crednerite, considerably bigger than anything previously discovered.

As a mining district, the Mendips produced chiefly lead ore, in the form of galena, but of its forms and method of occurrence practically nothing can now be seen, except for the few small lumps of massive mineral and bits of veinstone with occasional traces, that can here and there be picked up among the overgrown workings. Practically all the latter seem to have been in the Carboniferous Limestone, and small amounts have been found in calcite veins and pockets of soft yellow iron oxides in one or two of the quarries. It is also intermixed with some of the zinc ore that occurs in the Triassic Conglomerate. Crystals are not common, and these are rough and poorly formed.

Zinc was of secondary importance to lead and was not developed till the lead-mining industry had practically ceased in the eighteenth century: the carbonate, smithsonite, occurs in some quantity in the district,

particularly in the Triassic Conglomerate, and a period of active mining temporarily flourished and then faded out. The area round Shipham and Rowberrow appears to have been the centre of operations, but it was also worked in small quantities round East Harptree and later attempts were made at various places near Chewton Mendip. The ore is generally cellular or massive and earthy, and often intermixed with yellow iron oxides: large pseudomorphous crystals after calcite were at one time recorded,[1] but only a few small and inferior specimens have been found recently and then at other localities. Little now remains at the chief workings, but mounds of earthy debris containing a few rough lumps of smithsonite.

From the examination of a large number of specimens, it appears that the whole of the so-called 'calamine' from the Mendips consists of the carbonate, smithsonite; and though the silicate, hemimorphite, was recorded by Greg and Lettsom (loc. cit., p. 428), its occurrence has not been confirmed, and no specimens have been found by the writer, in spite of careful search, nor have any specimens from the district apparently been preserved in any collection. Blende occurs occasionally, in very small amounts, with the smithsonite and also in calcite veins in some of the quarries.

There are, in addition, a number of minerals whose occurrence in a limestone district is to be expected, and of which examples can be found at many places, but no specimens of sufficient mineralogical interest have been found to make it worth while enumerating the many localities where they occur: a brief mention of them will suffice.

In all the workings, calcite is abundant, as well as in the many limestone quarries in the district; it is usually as massive forms, but good crystals can be collected in some of the quarries. These crystals are generally scalenohedral, but rhombohedral and prismatic forms do occur. Baryte is often present, both in the old workings and in veins in the Carboniferous Limestone and Triassic Conglomerate, but in small amounts; most of it is massive or concretionary.

Iron oxides are widely distributed but usually in small amounts: they comprise haematite, hard and compact at some places, but more often soft and earthy; brown and yellow oxides coming under the general term limonite; and smaller amounts of crystalline and crystallized goethite. These oxides are sometimes accompanied by quartz.

Pyrite and marcasite have both been found, the former generally in

[1] R. P. Greg and W. G. Lettsom, Manual of mineralogy of Great Britain and Ireland, 1858, p. 425.

calcite veins, and the latter among the debris at one or two old workings, where it is much decomposed and accompanied by efflorescent growths of melanterite.

Pockets of manganese oxides, chiefly wad and pyrolusite, occur at several places at the junction of the Carboniferous Limestone and the Triassic Conglomerate, and many of the interesting minerals are associated with such deposits. Traces of manganese, as dendritic coatings and growths in veins and joints are also found at many places in the district.

Copper minerals are infrequent, and have been noticed only in very small quantities at one or two localities.

Chert occurs in bands in a number of quarries particularly round Frome, and hornstone is found among the debris at some of the old zinc workings.

Throughout the district, well-formed crystals are distinctly rare, except in the case of calcite, and when they do occur, they are generally very small.

Among the many localities visited are a number that may be mentioned in more detail, and in giving particulars of these, the method, used in working over the district, of taking it in sections, has been followed. In this, the area is divided into two sections, north and south, the northern section being dealt with first and the localities (nos. 1–11) taken from west to east; the southern section (localities nos. 12–15) being treated in the same way. References to the sheets of the 6-inch Ordnance Survey map of Somerset are given, and the approximate positions of the various localities, each of which is numbered, are shown on the accompanying sketch-map (fig. 1).

Locality No. 1.—Parish of Winscombe (Sheet XVII NE.), western end of Sandford Hill. At the north-western end of the upper part of a large quarry in the Carboniferous Limestone there is a series of large calcite veins. Several of these are manganiferous, and the following minerals occur in small quantities: pyrolusite, as dendritic coatings; galena, granular and as small rough cubo-octahedra; blende, in small stringer-veins; cellular smithsonite; pyrite; and small patches of malachite. Coarse cellular masses of brown iron oxides, often with a beautiful iridescent tarnish, occur in pockets in the limestone. Brown cuboid rhombohedra of calcite also occur in this quarry.

No. 2.—Parish of Compton Bishop (Sheet XVII SE.), on the north-east side of the south-eastern spur of Wavering Down, near Dunnett farm (south of the village of Compton Bishop) and 50 yards north-west

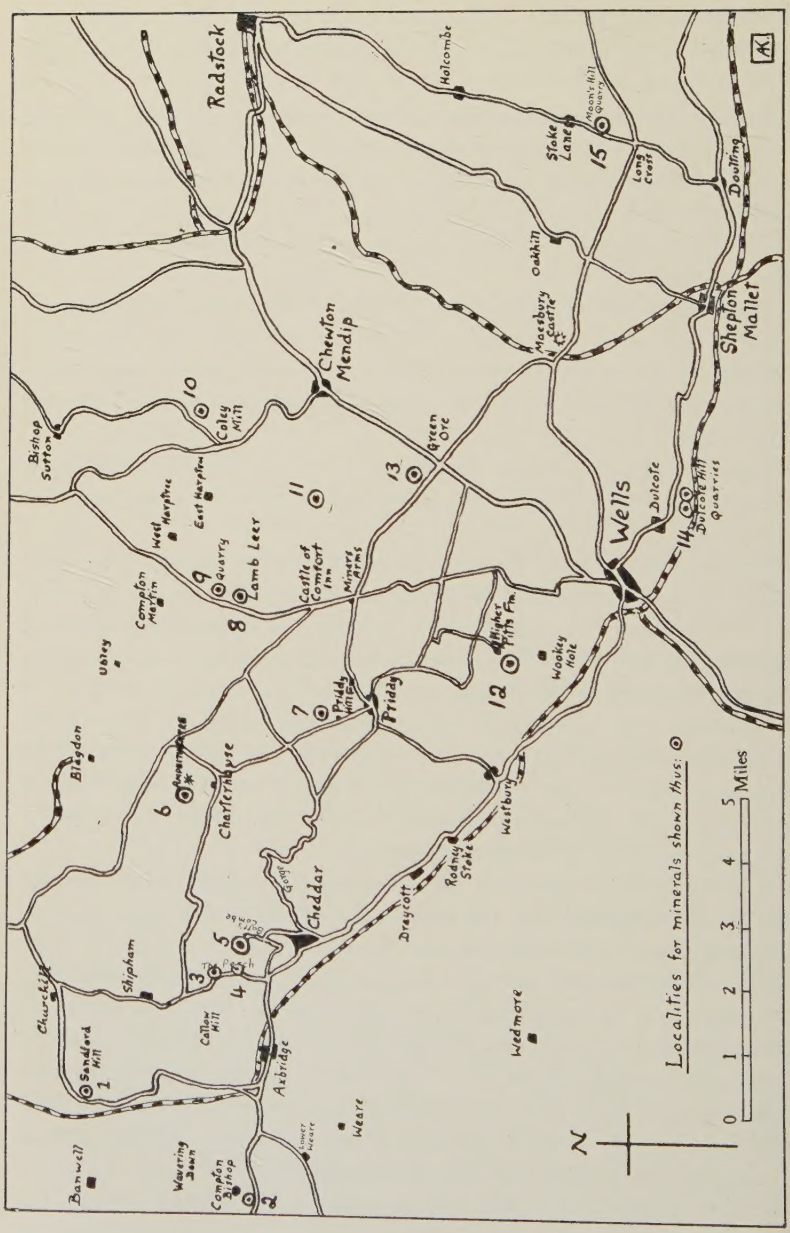

FIG. 1. Sketch-map showing mineral localities in the Mendip Hills, Somerset.

of the road to Loxton, whitish mamillated chalcedony occurs coating the brown iron oxide on the walls and floor of a small 'ochre cave'.

No. 3.—Parish of Cheddar (Sheet XVIII SW.), Bryant's quarry, one mile south-south-west of Shipham, on the east side of the road to Axbridge and in the part of Shipham Gorge known as The Perch (opposite the Callow Hill lime works). This is a large roadstone quarry in the limestone, and is at present disused.

Traces of fluorite were found here, for the first time in the district by the writer,[1] in November 1938, and some further and better specimens have since been collected. The mineral occurs as minute grains or thin veinlets, and as small crystals, up to 3 mm. across the faces, in rounded nodules of fine-grained granular calcite that are enclosed in the rock. The majority of the crystals are simple cubes (100), and tetrahexahedra of the general form (*hk*0), and combinations of the two forms. Many are well zoned, and range from colourless to very dark purple; the massive and granular material is dark in colour. In some cases the crystals are accompanied by tiny bright needles of goethite, little velvety-black hemispheres of haematite, or minute, but very brilliant, crystals of chalcopyrite. In one specimen, a number of very small brilliant orange-brown plates were present in a cavity; these were examined by Mr. F. A. Bannister of the Mineral Department of the British Museum of Natural History and found to be goethite with the form (010) and elongated parallel to the *c*-axis [001].

The fluorite is very scattered in its occurrence, and appears to be confined to the fine-grained calcite nodules, mainly in the south-eastern part of the quarry. So far, this is the only locality in the district where it has been found, and there are no records of its occurrence previously. A small patch has been noticed recently on one piece of limestone debris at the Waldegrave Lead Works, Priddy, but this is not *in situ*; and examination of the other debris and many of the neighbouring quarries has revealed nothing further.

No. 4.—Parish of Cheddar (Sheet XVIII SW.), just over $\frac{1}{4}$ mile south of Bryant's quarry, on the same side of the road, is another quarry, worked by the Axbridge Rural District Council. The main face is in Carboniferous Limestone, but at the western side the Triassic Conglomerate comes in and the junction is well exposed.

Calcite is abundant and good but small crystals can be collected; they are mainly scalenohedral, but rhombohedral and prismatic forms

[1] A. W. G. Kingsbury, A new British locality for fluorite in Somerset. Nature, London, 1939, vol. 144, p. 1013. [M.A. 7–503.]

also occur. In the conglomerate, small tufts of baryte are found, with dolomite, dendritic pyrolusite, and pyrite. Also very sharp and brilliant little pseudomorphs of goethite, with a thin skin of haematite, after pyrite; these occur, mainly in cavities implanted on granular dolomite, as cubo-octahedra, pyritohedra, and cubes, the last often as intergrown crusts. In several large cavities, at present exposed, malachite, pyrite, and chalcopyrite occur as inclusions in large rough scalenohedra of calcite.

No. 5.—Parish of Cheddar (Sheet XVIII SW.), Batt's Combe quarry, one mile north of Cheddar, on the west side of Batt's Combe. Calcite veins occur in the limestone and enclose small amounts of pyrite, chalcopyrite, malachite, and galena. In a large vertical vein at the southern end of the quarry face, one or two very small nests of pale yellowish-green pyromorphite have been found. This is a new locality on the Mendips for this mineral.

No. 6.—Parish of Blagdon (Sheet XVIII SE.), old workings $\frac{5}{8}$ to $\frac{3}{4}$ of a mile north-north-west of Charterhouse farm, and about 500 yards west-north-west of the Roman Amphitheatre, marked on the map as 'Lead Mine (disused)'.

The discovery in 1936 of a number of minute fragments of a green mineral among the debris scraped out by rabbits at these old overgrown workings led to the finding of a large number of small pieces of cellular pyromorphite; one or two fair-sized pieces have since been obtained, and, from the position and general lay-out of the workings, there is no doubt that this is the old locality from which John Woodward obtained the specimens mentioned in his catalogue (1728, vol. 2, part 1, p. 27) as from 'Green-hill, near Charter-house'. Hitherto beyond those in Woodward's collection now at Cambridge, no other specimens of this mineral from the Mendips seem to have been recorded or preserved (except the small specimens collected by the writer at Higher Pitts farm and Batt's Combe quarry, localities nos. 12 and 5). A number of minute prismatic crystals are present on some of the specimens lately found, and a few of the latter are of good colour; otherwise they are dull and generally coated with pinkish clay. The mineral occurs, apparently as ribs and impregnations, in the Old Red Sandstone. In spite of digging operations on the dumps made in company with Mr. Arthur Russell last year, in the hope of obtaining some better specimens, very little was found.

No. 7.—Parish of Priddy (Sheet XXVII NE.), Priddy Hill farm, $1\frac{1}{2}$ miles north-north-west of Priddy church. At an old pit about 600

yards north of the farm and about 200 yards east of the road, just outside a small plantation, iron and manganese oxides occur in the Triassic Conglomerate, and from the dump of this pit a small piece of mendipite was recorded by Dr. Spencer in 1923. Two further small pieces have since been found, but none of the other minerals that occur under similar conditions at Higher Pitts farm, near Priddy, seems to be present.

No. 8.—Parish of West Harptree (Sheet XIX SW.), Lamb Lair cavern (more properly Lamb Leer), on Gibbet's Brow, just over one mile south of Compton Martin, on the Wells road. The most interesting occurrence in this cave is a bed of white crystalline aragonite, which at one time sealed up the entrance passage down into the main chamber. The bed varies from 6 inches to about 2 feet in thickness and is of very fine grain with a laminated structure.

No. 9.—Parish of West Harptree (Sheet XIX SW.), limestone quarry 200 yards north of the entrance to Lamb Lair cavern. The north wall of this quarry, which is one side of a fissure extending across the working-face, is in places coated with a deposit of iron oxides, cavities in which are lined with crusts of brilliant velvety goethite needles and small bipyramido-prisms of quartz. These specimens of goethite, though small, are among the best found in the district.

No. 10.—Parish of Hinton Blewett (Sheet XIX SW.). During the excavation of some holes for the erection of a line of electricity pylons in 1937, about 400 yards north of Coley Mill, a number of fair-sized lumps of a whitish fibrous mineral were found in the Triassic marl. It was stated to be gypsum, but its weight was noticeable, and examination by Mr. Arthur Russell and the writer of some specimens recently obtained has proved it to be celestine. The mineral is opaque on the outside of the nodules, and, except for a thin layer stained pink from contact with the marl, is generally pure white; internally it is fresh and translucent, and in some specimens has a very pale bluish tinge. It is some of the finest fibrous celestine that has been found in the British Isles, where this form is not common.

No. 11.—Parish of Chewton Mendip (Sheet XXVIII NW.), old workings in a field known as 'All Eights' just west of Eaker Hill farm, $1\frac{1}{8}$ miles west-south-west of Chewton Mendip church. This locality is only of interest for the finding of a remarkable specimen of dendritic galena, which was picked up on the waste-heap of a pit about half-way along the north-west boundary fence. Only one small specimen was found.

No. 12.—Parish of St. Cuthbert Out (Sheet XXVII SE.), Higher Pitts farm, $1\frac{1}{2}$ miles south-south-east of Priddy church. The minerals found at this locality are numerous and comprise the following:

Haematite, goethite, and various brown and yellow iron oxides; quartz, generally as doubly terminated crystals on goethite; calcite; pyrolusite, earthy, fibrous, and granular; wad, earthy and botryoidal and, on one small dump near the farm-house, hard and compact; manganite, as small acicular crystals, granular, and as fibrous aggregates; psilomelane, one small specimen of thin columns penetrating mendipite; compact massive white manganocalcite; pink manganiferous dolomite; malachite as minute crystals and as stains and small earthy patches; chessylite, one or two minute patches of earthy material on calcite.

Cerussite, compact masses or loose rough crystals and nodules fill cavities in the manganese ores; three specimens of rather corroded but reasonably well-formed twinned crystals have been found, but their occurrence is unusual.

Hydrocerussite ($2PbCO_3.Pb(OH)_2$) occurs in some quantity, embedded in the manganese oxides or with calcite, as compact masses or rough crystals, up to 6 cm. across.

Mendipite ($2PbO.PbCl_2$) occurs under similar conditions as hydrocerussite and is often surrounded by and partly altered into hydrocerussite and/or cerussite, with small amounts of crednerite and malachite. Upwards of sixty specimens have been found, but the majority do not exceed 2 cm. in length; a few nodules up to 5 cm. were obtained and one really good one, which was some 16 cm. long and 4 cm. thick, and, freed from its matrix, weighed $2\frac{1}{2}$ lb.

Chloroxiphite ($2PbO.Pb(OH)_2.CuCl_2$) and diaboleite ($2Pb(OH)_2.CuCl_2$), two rare minerals first described by Dr. Spencer in 1923, are found, often associated together, in the mendipite at this locality. The former usually occurs as thin blades or aggregates enclosed in mendipite, but diaboleite also occurs as minute crystals in hydrocerussite and cerussite. A further number of good specimens have been found in which the chloroxiphite is in aggregates up to 1 cm. in thickness and diaboleite is also present in some quantity.

Crednerite ($CuO.Mn_2O_3$), a considerable number of specimens have been collected, but most of these are small, with the exception of two. In the first of these the crednerite plates cover an area about 4×2 cm. but are thin; in the second and larger specimen, the crednerite consists of a single large rough crystal, some $6 \times 3\frac{1}{2}$ cm. and 4 cm. thick, and is

probably one of the finest specimens of this mineral in existence. Both these were found in March last year.

Mimetite, numerous further specimens have been obtained but they are small. In one case a number of fine acicular prismatic crystals, of great brilliancy and lustre, occurred in a cavity. They are bright orange-yellow in colour and perfectly formed but do not exceed 2 mm. in length. The usual mode of occurrence is as rounded crystalline aggregates.

Wulfenite ($PbMoO_4$), the occurrence of three very small specimens of this mineral was recorded by Dr. Spencer in 1923. In view of its rarity as a British species, a careful search has been made and ten or eleven further specimens have been found. While in no way comparing with some foreign examples as mineral specimens, they are, for British specimens, reasonably good, and in two cases large. They consist of rough crystals, from 1 to 3 cm. across and up to 5 mm. thick, and pale wine yellow in colour. The best specimen was a nodule of pale massive material, some 4 cm. long and $2\frac{1}{2}$ cm. thick, at one end of which a crust of small intergrown tabular crystals project into a cavity in the matrix; though small, these crystals are bright and well formed and deeper in colour than the other specimens.

Aragonite is uncommon and has only been found in two specimens of any size. In these it formed the matrix of two large nodules, partly altered to calcite, on the outside of which most of the specimens of wulfenite were found. A few minute needles are occasionally associated with small nodules of hydrocerussite.

In addition to these minerals, the following have also been found and are new to the locality:

Pyromorphite, two small specimens, consisting of pale yellowish-green rounded crystalline aggregates lining cavities in calcite and wad.

Baryte, only one very small specimen has been noticed.

Rhodochrosite, this was first found in 1934 as a nodule of compact massive material, some 10 cm. long, embedded in the hard manganese ore on a small dump near the farm-house. Though pale in colour it is remarkably pure and contains hardly any calcium. Further small specimens have since been found, chiefly massive, but some are botryoidal crusts or rounded crystalline aggregates lining cavities. This mineral had not been previously recorded from the Mendip district.

Tetrahedrite has been found in very small amounts by Mr. Arthur Russell.

Vo. 13. Parish of Chewton Mendip (Sheet XXVIII SW.), old work-

ings some 400 yards north-west of the hamlet of Green Ore, $2\frac{1}{2}$ miles south-south-west of Chewton Mendip on the main road to Wells. This ground, known as 'Miles's Lot', was at one time worked for zinc ores and the following minerals occur in small amounts on the waste-heaps: calcite, iron oxides, smithsonite, baryte, galena, quartz, and hornstone.

On a small dump towards the north-eastern corner there is a good deal of cellular smithsonite banded with layers and rounded nodules of baryte. Small veins of cadmiferous blende occur in this material, and in these veins of blende are occasional small patches and veinlets, up to 1 mm. thick, of a bright canary-yellow mineral very similar to that found at Mill Close mine, Darley Dale, Derbyshire. The colour is clearly due to cadmium, and the mineral may be a form of earthy greenockite;[1] but Mr. F. A. Bannister has not been able to confirm this by an X-ray powder photograph, which showed only the lines of smithsonite.

No. 14.—Parishes of Dinder and St. Cuthbert Out (Sheet XLI SW.), Dulcote Hill quarries, on the south side of Dulcote Hill, 2 miles south-east of Wells. This is a good locality for calcite as large well-formed crystals and massive varieties.

No. 15.—Parish of Stoke Lane (Sheet XLII NW.), Moonshill quarry, half a mile south of Stoke Lane, and three miles north-east of Shepton Mallet. This is a large roadstone quarry in the pyroxene-andesite of the eastern Mendip Silurian inlier. The rock contains pseudomorphs of bastite, with small veins and patches of quartz, dolomite, calcite, chlorite, and other decomposition products. Epidote also occurs as fine granular material coating faces of joints and as minute, but very brilliant, crystals in cavities, often accompanied by small crystals of quartz; and it is worthy of note as being the only occurrence of this mineral, not only in the Mendip district, but also over a very considerable area of this part of the country. Small amounts of a bright-red soft fibrous mineral also occur, generally much intermixed with chlorite. This has been examined by Mr. F. A. Bannister and found to be laumontite, which has not been recorded from the district before.

The chief interest, however, is in the occurrence of small amounts of copper minerals, in a ridge of rock that formerly separated the north and south parts of the quarry, but which has now been entirely worked away. These minerals comprise chalcosine, chrysocolla, cuprite, mela-

[1] A. W. G. Kingsbury and J. N. Friend, Occurrence of greenockite in the Mendips. Nature, London, 1939, vol. 144, p. 1013. [M.A. 7–503.]

onite, covelline, and malachite. They occur coating joint-planes or in hin veins and patches in the rock immediately adjoining the joints, but nly in very small amounts. With the exception of malachite, none of hese copper compounds appears to have been previously recorded from he district.

The writer would like to record his thanks to Lord Waldegrave, of he Priory, Chewton Mendip; Mr. A. E. Culliford of Higher Pitts farm; d:. Symes of Green Ore, Chewton Mendip, and to all those many land-wners, quarry-owners, and others, too many to name individually, who ave assisted, by giving permission to look over and work on their roperty, or in other ways; and also to express his great appreciation o the following: Dr. L. J. Spencer, for his valuable and encouraging elp, especially in the first few years of these investigations; Dr. F. S. Vallis, of Bristol Museum; Mr. Arthur Russell, of Swallowfield Park, Reading; Lieut.-Colonel W. Campbell Smith and Mr. F. A. Bannister, f the Mineral Department of the Natural History Museum, London; nd Dr. J. Newton Friend, of Birmingham Central Technical College, or their great help in identifying and confirming the identity of many pecimens, and in various other directions; and to Mr. H. E. Balch of Vells Museum, for his valuable suggestions and help in tracing and ringing to the writer's notice many localities in the district for in-estigation.

To conclude, it may be of interest to give a list of all the species, ncluding one or two varieties, that have been found in the district. With three exceptions, where the name of the authority for the occur-nce is given, specimens of all of the following minerals have been ollected recently by the writer. They are set out in chemical groups, ccording to Dana's classification.

Sulphides, &c.

alena
halcosine
lende
ovelline
halcopyrite
yrite
arcasite
etrahedrite (Mr. Arthur Russell)

Haloids

luorite
ryolipite
hloroxiphite
ioboleite

Oxides

Quartz
Chalcedony
Cuprite
Melaconite
Haematite
Crednerite
Pyrolusite
Goethite
Manganite
Limonite
Red and yellow ochre
Psilomelane
Wad

CARBONATES

Calcite
Manganocalcite
Dolomite
Rhodochrosite
Smithsonite
Cerussite
Aragonite
Malachite
Chessylite
Hydrocerussite

SILICATES

Epidote
Laumontite

SILICATES (*cont.*)

Chlorite
Chrysocolla

PHOSPHATES, &c.

Pyromorphite
Mimetite

SULPHATES, &c.

Baryte
Celestine
Anglesite in slags (Dr. L. J. Spencer)
Leadhillite in slags (Dr. L. J. Spencer)
Melanterite
Wulfenite

Dravite-bearing rocks from Dinas Head, Cornwall.

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[Read June 6, 1940.]

IN a previous paper [1] describing the geological and petrographical details of the adinoles of Dinas Head, short references were made to the common occurrence among the adinoles and associated rock-types of the magnesia-rich tourmaline, dravite. It is proposed now to describe these tourmaline-rich rocks in more detail and to discuss the question of their origin.

Distribution of Dravite-bearing Rocks.

Adinoles with accessory tourmaline occur wherever true adinoles are developed at Dinas Head, although tourmaline is characteristically absent from types 2 *a*, *b*, *c*, and 3 [1, pp. 318–323]. Bands with up to 30 % tourmaline occur interbanded with normal adinoles of type 1 and with certain spilosites.

Rocks composed entirely of the tourmaline are confined to two localities: the first is at the top of the cliff on the north side of Dinas Head just below the faulted junction of the adinoles with the slates and limestones; the second is on a small shelf of folded adinoles just above high-water mark on the north side of the headland facing Stinking Cove.

Petrography.

1. *Dravite-bearing spilosites.*—Descriptions and figures of these rocks, and an account of how they grade into dravite-bearing adinoles have already been published [1, pp. 314–315].

2. *Dravite-bearing adinoles.*—A preliminary account of these rocks has already been given [1, pp. 318], but for convenience of reference the main types into which it is convenient to group them will be summarized here and the previous descriptions amplified only where rendered necessary by more recent work.

a) Isolated rods or tufts of dravite needles of approximately the same size as the minerals in the groundmass of the adinole may be

randomly distributed or concentrated in certain bands accentuating the original fine banding of the rock.

(*b*) The tourmaline crystals are similar to those in (*a*), but occur in small pools or as bands of inwardly directed needles enclosing adinole similar to, but coarser in grain-size than, that forming the main part of the rock.

(*c*) In the hand-specimen, some adinoles show a fine banding due to carbonate. In slice these rocks are seen to be composed of a base of a fine intergrowth of quartz and albite with evenly scattered granules of leucoxene and a little chlorite as in the normal adinoles. In this are narrower bands, often lenticular, composed of coarser crystals of albite enclosing crystals of dravite, either as radiating tufts or as little groups parallel to the albite twin-plane (fig. 1A). Marginally, these bands show concentrations of ankerite (dolomite 70, Fe-dolomite 30 %) as irregularly bounded crystals with a tendency to develop rhombohedral outlines. These are often associated with narrow cross-cutting veins of similar carbonate, but albite, when present in these veins, is never coarse-grained or with inclusions of acicular dravite. Occasionally small patches of zoisite occur. It is evident here that the introduction of carbonates was not responsible for the increase in grain-size of certain bands, but that they travelled along these already coarser bands as being the easier way. The increase in grain-size of the albite may be associated with an introduction of boron-rich solutions after the albitization, or to some effect of the initial composition of a banded sediment on simultaneously introduced sodium- and boron-rich solutions.

(*d*) Belts of dravite and patches of adinole show coarser areas which are mainly pools of quartz enclosing needles of dravite and rutile.

In all these types the dravite has the same optical properties: colourless to very pale green with average refractive index values of ω 1·631, ϵ 1·610.

3. *Dravite-sericite-rock.* –This is a pale greeny-white, somewhat fissile rock, weathering with many small excrescences, which occurs interbanded with normal, sheared, and spherulitic adinoles on the north side of Dinas Head. In slice, the base consists of poorly orientated sericite showing little tendency to envelop the tourmaline, together with evenly scattered granules of leucoxene. Set in this groundmass are rather irregular, though in general rounded, masses of dravite from one to two millimetres in diameter. Each of these is made up of a bundle of needles of dravite (ω 1·630, ϵ 1·611) in patchy parallel growth, and showing a zonary distribution of colour from a dark grey, rather opaque

border to a colourless inner zone with pale brown faintly dichroic patches (fig. 1B). Partial analysis of this rock gave SiO_2 57·80, B_2O_3 3·94 %.

4. *Dravite-rocks.*—These rocks are hard and dull or creamy grey in colour and are distinguishable from adinoles by their rather waxy lustre. They may be considered conveniently in three groups.

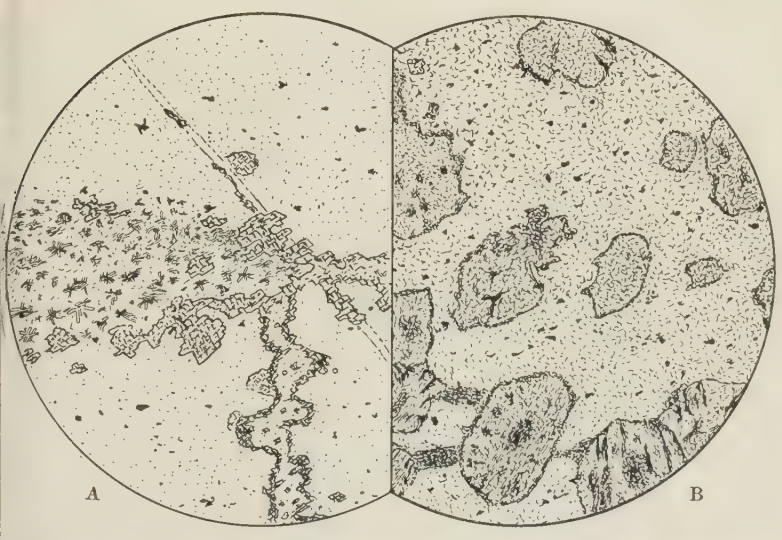

FIG. 1A. Adinole with band containing dravite needles and veined by ankerite. ×16.

FIG. 1B. Dravite-sericite-rock, showing parallel growths of dravite set in unorientated sericite. ×8.

(*a*) Hard, dull grey rocks of very fine grain with an irregular fracture and very fine clear banding. With increasing alteration these types show a slightly more flinty fracture, a less perfect banding, and the development on the weathered surfaces of small pinky-white spots about half a millimetre in diameter. The parent rock of these types is not known with certainty: that it was a sediment is suggested by the fine banding; in some cases it may have been a slaty type, for, although no two specimens are alike, it is possible under the microscope to select a series showing a transition from a sericite-rich rock to one composed essentially of dravite and illustrated by the following three stages:

(i) The least altered type (fig. 2) consists of a base of fine-grained sericite, in which patches of minutely fibrous, colourless tourmaline have developed. Leucoxene granules are evenly distributed throughout.

Qualitative chemical tests were necessary to prove the abundant boron in this rock as the grain-size does not permit accurate optical identification.

(ii) In the succeeding stage of alteration all the sericite is replaced by needles of dravite. The tourmaline is colourless or very pale brown, a slight mottling which appears in the slice being due probably to

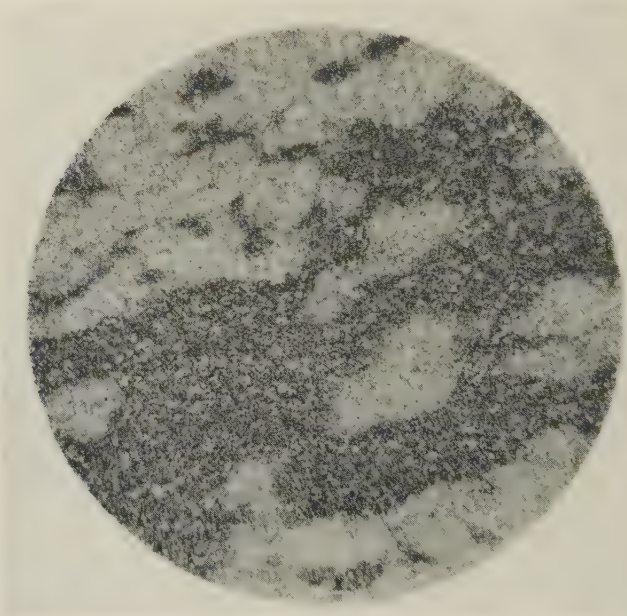

Fig. 2. Dravite-sericite-rock, showing sericite (light) partially replaced by dravite (dark). Crossed nicols, ×30.

bundles of these very small needles (±0·01 mm. in length) in parallel orientation. The banding is marked by small granules of leucoxene which is insoluble in hydrofluoric acid and may therefore be anatase, and by films of carbonaceous material. Partial analysis of this rock gave SiO_2 45·59, B_2O_3 7·24 %.

(iii) Without any increase in grain-size, type (ii) passes into types which show large patches of minute needles in parallel orientation, generally with the *c*-axes lying in the plane of the banding. Often the slice has a woven appearance between crossed nicols owing to two sets of interlacing needles. Very occasionally a single idiomorphic tourmaline may be observed with ω colourless, ϵ pale olive-green. These may represent, in part, detrital tourmaline in the original sediment, but this

cannot be proved. Fine granular calcite occurs commonly, either as bands in the groundmass or more or less evenly distributed. Isolated crystals of quartz and albite enclosing long needles of dravite occur: these crystals are irregular in outline and around them the felt of dravites is extra dense. Randomly distributed throughout the rock are small grains of a mineral not yet identified, but whose properties are recorded as colourless, two cleavages, straight extinction, and refractive index approximately 1·62, double refraction about 0·010. Partial analyses of this rock gave SiO_2 44·32 and 43·01, B_2O_3 7·01 and 7·12 %. The values for B_2O_3 are only 2 % lower than those for average dravites, so that if the rock is largely tourmaline, a supposition supported by X-ray powder photographs, there is present 70–80 % of dravite. The analyses also show that the change from the fine-grained 4 *a* (ii) to the coarser 4 *a* (iii) must be a physical one.

(*b*) Pale, milky-grey, fine-grained rocks breaking with a dull, waxy fracture. They all show some banding, but generally as coarser structures than in the types just described. Macroscopically, the three main types show the following features:

(i) Fine banding without change in grain-size.

(ii) Banded lenticles elongated in the 'bedding' planes, the lenticles appearing harder and glassier than the rest of the rock and somewhat like chalcedony.

(iii) Fine parallel bands of a white powdery material in the usual fine-grained base.

Microscopically, the corresponding slices show:

(i) Needles of colourless dravite about 0·01 to 0·10 mm. in length, but otherwise showing all the characters of the tourmaline described in the most highly altered types of 4 *a* (iii). The banding is seen to be due to fine granular calcite and to the better parallel-growth development of the tourmaline fibres.

(ii) A base similar to (i) but with even better alignment of the needles in the bedding planes. The glassy bands and beads are revealed as well orientated, coarse parallel growths of dravite, usually with a marginal concentration of granular calcite and relatively free from leucoxene (fig. 3). Sometimes broad bands suggesting a vague sector twinning may be seen in these areas. Narrow veins with quartz, cricite, calcite, and a little pyrite cut sharply across the rock. Partial analysis gave SiO_2 39·41, B_2O_3 8·04 %. These figures approximate to the values for actual dravites more closely than do those for 4 *a* (ii) and *a* (iii), and suggest that this rock has been more completely replaced.

(iii) The groundmass consists of a fine-grained interlocking mass of colourless or very faintly green needles of dravite, each about 0·05 to 0·10 mm. long and arranged in a random manner with accompanying granules of leucoxene and carbonates. In this are seen patches and bands corresponding to the white powdery material of the hand-specimen,

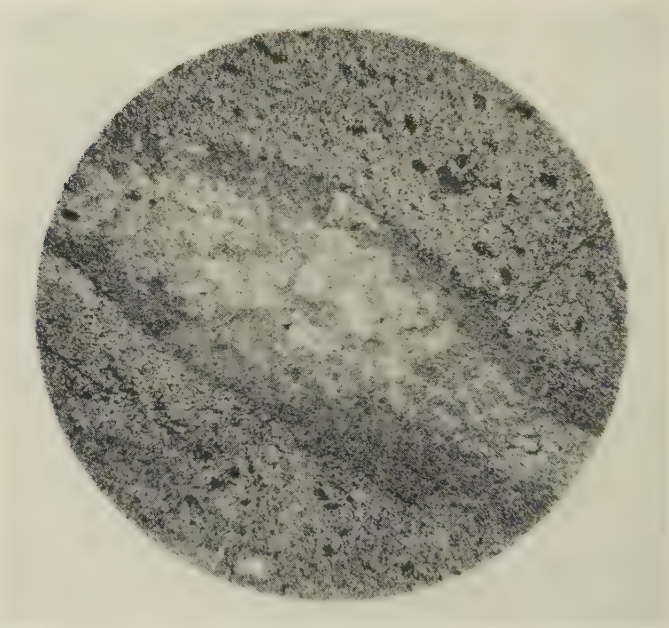

Fig. 3. Dravite-rock, showing large parallel growth of dravite needles set in a fine-grained groundmass. Crossed nicols, × 20.

and in which the needles may be up to 0·25 mm. in length. These have the same optical properties as those of the groundmass, ω 1·631, ϵ 1·610, and are arranged in a criss-cross manner with no interstitial material. There also occur occasional pools of quartz with inclusions of dravite needles. Partial analysis of this rock gave SiO_2 46·10, B_2O_3 7·75 %. The unidentified mineral already referred to has been recognized in these three types.

(*c*) Spherulitic dravite-rock. This is a fine-grained, waxy, green-grey rock showing some banding accentuated by bands rich in calcite. Microscopically, it is seen to consist of a mass of small spherulites of colourless dravite ranging from 0·02 to 0·06 mm. in diameter, with ω 1·632, ϵ 1·610. Leucoxene and calcite occur in granular form through-

TABLE I. Chemical analyses of dravite.

	1.	1A.	B.	C.	D.	E.	F.	G.
SiO_2	38·84	39·73	38·30	36·57	36·80	36·52	35·96	36·41
TiO_2	1·01	nil	0·15	0·36	0·18	0·17	0·14	1·61
Al_2O_3	36·48	37·32	36·99	35·01	37·14	33·41	30·85	31·27
B_2O_3	8·64	8·84	10·38	9·78	9·63	10·32	10·73	9·65
Fe_2O_3	0·26	0·26	trace	trace	0·18	n.d.	n.d.	nil
FeO	0·60	0·61	0·22	1·12	1·80	0·30	0·76	3·80
MnO	nil	nil	0·01	0·01	trace	0·57	—	trace
MgO	6·96	7·12	8·90	11·40	8·33	11·25	13·67	9·47
CaO	0·52	0·53	nil	0·37	0·11	0·42	2·41	0·98
Na_2O	1·21	1·24	1·88	1·39	1·60	2·34	1·63	2·68
K_2O	0·64	0·65	nil	0·25	0·08	0·57	0·09	0·21
Li_2O	nil	nil	0·16	nil	nil	—	—	nil
H_2O+	3·62	3·70	3·55	4·46	4·48	3·76	4·16	3·79
H_2O-	0·88	nil	nil	nil	0·10			
F	trace	trace	0·07	n.d.	n.d.	0·12	n.d.	nil
Total	99·73	100·00	100·61	100·72	100·43	99·75	100·40	99·87
Sp. gr.	—	—	3·03	3·03	3·03	3·038	3·05	—
ω	—	1·631	1·634	1·635	1·636	1·6355	1·637	—
ϵ	—	1·610	1·612	1·612	1·614	1·6130	1·616	—
$\omega - \epsilon$	—	0·021	0·022	0·023	0·022	0·0225	0·021	—

1. Spherulitic dravite-rock associated with adinole, Dinas Head, Cornwall. Analyst, W. H. Herdsman. Also Cr_2O_3 0·07.

1A. The same recalculated to 100 % less TiO_2 and H_2O-.

B. Dravite replacing granite, Karragullen, Western Australia. Analyst, D. G. Murray in E. S. Simpson, 1931.

C. Dravite from quartz-dravite vein in granite, Swan View, Western Australia. Analyst, E. S. Simpson, 1931.

D. Dravite from spherulitic quartz-dravite vein in granite, Jarrahdale, Western Australia. Analyst, H. P. Rowledge in E. S. Simpson, 1931.

E. Dravite from talc-schist, Dobrova, Carinthia. Analyst, W. Kunitz, 1929.

F. Dravite from Gouverneur, New York, U.S.A. Analyst, W. Kunitz, 1929.

G. Dravite in marble, Monroe, Connecticut, U.S.A. Analyst, R. B. Riggs, 1888.

out the rock and by being concentrated in certain layers accentuate the banding. An occasional grain may be seen of a mineral agreeing fairly closely with apophyllite. The chemical composition of this rock, determined after removing all the calcite with dilute hydrochloric acid is given in table I, column 1. Column 1A is the same analysis recalculated to 100 % after the removal of the values for H_2O (—105° C.) and for TiO_2, on the assumption that all the latter is present as leucoxene. Calculating on a basis of O_{93}, these analyses correspond respectively to

1. $H_{11\cdot71}(K_{0\cdot40}Na_{1\cdot14}Ca_{0\cdot27})(Mg_{5\cdot04}Fe^{++}_{0\cdot24}Fe^{+++}_{0\cdot09}Al_{20\cdot89}Ti_{0\cdot37})B_{7\cdot21}Si_{18\cdot87}O_{93}$

1A. $H_{11\cdot80}(K_{0\cdot40}Na_{1\cdot15}Ca_{0\cdot27})(Mg_{5\cdot08}Fe^{++}_{0\cdot24}Fe^{+++}_{0\cdot10}Al_{21\cdot06})B_{7\cdot30}Si_{19\cdot01}O_{93}$,

that is approximately to $H_{12}Na_2(Mg_6Al_{21})B_7Si_{19}O_{93}$. If the structural formula of tourmaline is assumed to be $X_3Y_{27}B_9Si_{18}H_xO_{93}$, and it is

borne in mind that these figures are based on the analysis of a rock as distinct from that of a mineral, the agreement must be considered as very close, and would be closer still, and correct, to some extent, the low value of the X group, if the calculation was based on B_9 instead of on O_{93}.

Detection of Tourmaline.

In most of these rocks, the dravite is either too fine-grained or else present in amounts too small to permit the certain identification of the mineral in thin section. For separating the actual mineral, the insolubility of tourmaline in cold hydrofluoric acid was relied upon, and the refractive indices recorded were always obtained on material treated in this manner.

In some other cases, the detection of boron was effected by chemical means, using the methyl borate method. As this proved only that boron was present and not necessarily that the mineral was tourmaline, X-ray powder photographs were taken of those rocks in which the chemical analysis showed large amounts of B_2O_3 approximating the theoretical amount in tourmaline, and the spacings calculated and compared with the results obtained from a crystal of undoubted tourmaline. Although, in most of the specimens, comparatively few lines could be measured, the results which were obtained are consistent with the rock being composed mainly of tourmaline.

The Origin of the Dravite-bearing Rocks.

The occurrence of dravite in adinoles as described from Dinas Head is unique, but in order to elucidate the relation of the boron to the albite-dolerite, it is necessary to consider the recorded occurrences of similar magnesia-rich tourmalines.

At Renfrew, Canada, dravite-uvite occurs in the Grenville limestone at its contact with a pyroxene-bearing granite-gneiss (Bruce, 4). In Madagascar, dravites occur associated with phlogopite-bearing granite-pegmatites where these cut pyroxenites, talc-schists, and crystalline limestones (Lacroix, 12). At Monroe, Connecticut, and Pierrepont, New York, U.S.A., dravite-uvites occur in chlorite-schists cut by granite-pegmatites (Riggs, 18). At Dobrova, Carinthia, and Gouverneur, New York, U.S.A., dravite occurs in talc-schists and dolomitic limestones cut by granite-pegmatites (Kunitz, 10). At Muruhatten, Sweden, ferriferous dravite occurs in migmatized serpentines and amphibolites (Du Rietz, 16, 17). In the Darling Range, Western Australia, dravite

both replaces the granite and is found in it, accompanied by quartz, as joint infillings. It is described as being, in some cases, finely spherulitic, in others as so finely fibrous as to be obscure even under the microscope except between crossed nicols (Simpson, 23). In the Urals, ferriferous dravite is found in a serpentine near its contact with a Devonian limestone. The whole district is cut by granite-pegmatites (Duparc and Sigg, 6). In the Pyrenees, dravite occurs in metamorphosed marls and limestones, and schorl is found in shales at the contacts of many lherzolite masses. Here the tourmaline is everywhere associated with scapolite. It also occurs in the gypsum-anhydrite-albite-scapolite-leuchtenbergite-rocks at the contact of ophite intrusions, where it is considered to be a product of the metasomatism of gypsum deposits by the ophites (Lacroix, 11).

There has been a tendency to regard tourmalines of the dravite-uvite series as being the tourmalines characteristically associated with basic igneous rocks, but a critical examination of the available evidence suggests that this conclusion is not justified. In all but the last of the occurrences cited above a granitic source of the boron is available, and even in the case of the Pyrenean occurrences, more recent workers differ from Lacroix in their interpretation. Bertrand [3] considers that the metamorphism of the Mesozoic sediments is of a regional type, due to the burial of these sediments in the north Pyrenean Cretaceous geosyncline, and that the boron and chlorine were derived from the granite masses at depth in the region of injection. Longchambon [13] agrees with Bertrand on the grounds that not only may the tourmalinized and scapolitized rocks be found away from any lherzolite or ophite contact, but that they also occur at a constant tectonic horizon, that which had been buried deepest in the geosyncline. The boron is regarded as having been derived from a granitic magma at depth and the scapolitization produced by the action of this magma in distilling chlorine out of the saliferous horizons of the Trias, to be fixed in rocks of suitable composition (marls) in the overlying Jurassic and Cretaceous strata.

In the case of the dravite-scapolite-anhydrite-rocks associated with the ophites, it must be borne in mind that the boron here may be derived from borates in the original gypsiferous deposits.

In the example studied by Duparc and Sigg [6], the authors suggest that it is possible that a nearby granite may be the source of the boron, but in addition they point out that there is no reason why the basic igneous rocks should not contain the same volatiles as acid ones.

Support is lent to this idea by records of two other boron and basic rock associations, although in neither case is boron present in any large amount. Andreae and Osann [2] note the presence of tourmaline, a schorl, in a quartz-rich hornfels at the contact of the Palisade diabase, U.S.A. Walker [25] found 0·18 % B_2O_3 in a Scottish tholeiite, and came to the conclusion that this could be present only in the interstitial glass.

A more obvious association of boron and basic igneous rocks is shown by the development of datolite, such as has been described from the basalts and dolerites intrusive into the Trias of the Atlantic States of America by Cook and Kraus [5], Hawkins [8], Manchester [14], and Shannon [19–22]. Here datolite is associated with an end-stage assemblage of zeolites, calcite, and chlorite, either as veins cutting the dolerites, basalts, and contact-rocks or as vesicle infillings; in the latter case the source of the boron from the basic igneous rock seems certain. Many other occurrences of allied mineral associations are known, but except for a few occurrences, e.g. Monte Campotréra, Italy, described by Ferrari [7], these have not been fully investigated.

In the above cases there are no immediately associated granitic types, which, as in the case of the dravites previously described, could have been an alternative source of the boron.

The occurrence, described by Slavík and Fišer [24], of a shale at the contact of a diabase being converted into a fine-grained porcellanous datolite rock is the best example of the production of datolite as the result of boron metasomatism, associated with a basic igneous rock. It may be that at low temperatures in a lime-rich environment datolite is formed and at a higher temperature a tourmaline of the dravite-uvite series; there is, however, no decisive evidence on this point.

From a consideration of the evidence supplied by the descriptions of the known occurrences of magnesia-rich tourmalines, the following conclusions are drawn:

1. Like all other types of tourmaline, the source of the boron or of the tourmaline as such is a granitic magma.

2. In all cases, except that of the Darling Range granite, the presence of Ca and Mg in the Y group of the tourmaline is controlled by the composition of the mineral or rock with which the tourmaline is developed.

The ubiquity of the granite-tourmaline association would suggest that at Dinas Head also, the tourmaline is of granitic origin, but before a conclusion based on such general probabilities only can be accepted,

the more particular data which suggest that the albite-dolerite may be the source of the boron must be examined.

Dravite has not been found away from the adinoles and their related rocks and the constant association of the albite and dravite suggest a common and contemporaneous origin of the boron and sodium. In the development of spilosites and spilositic adinoles, dravite is found associated with the albite in the initially formed spots of the spilosites, and also, as a second generation, in the coarser patches corresponding to these spots in the groundmass of the spilositic adinoles. When first described [1, p. 333], these features were regarded as signs of the simultaneous addition of boron and sodium. It is now recognized that this same arrangement is that which would be expected had the dravite formed later, having been able to grow as larger crystals in the coarser spots than in the finer groundmass. Certain other adinoles, in which dravite is found only in the coarser bands, support this argument, but without indicating whether the boron was introduced at the same time as the sodium or later.

The dolerite shows little axinitization and very little, if any, of the effects of the thermal metamorphism which has altered the rocks with which it is so intimately connected in the field, whereas at granite contacts at other localities, rocks similar to this albite-dolerite have been observed to be very susceptible to these effects. Thus it may be argued that the albite-dolerite must be the cause of any such changes in its neighbours.

Against the acceptance of this view in its entirety are the facts that the albite-dolerite, unlike the Cornish granites characterized by boron-bearing aureoles, contains no boron-bearing accessory minerals, whereas it is rich in a soda mineral, albite, and has undoubtedly caused much soda-metasomatism. The axinite described from a gash vein is better interpreted as having been formed after the consolidation of the basic rock.

From this evidence, weighted by the conditions of other dravite occurrences, it must at present be concluded that the albite-dolerite was the cause of the thermal metamorphism of the bedded rocks and of their subsequent adinolization; and, more tentatively, that the tourmalinization is due to a hypothetical granite emplaced under conditions such that only boron-bearing fluids were able to affect the rocks now exposed at Dinas Head, and that the albite-dolerite was either physically impermeable to, or chemically stable in the presence of these fluids. Perhaps the elevation in temperature associated with this was

responsible for the development of the spherulitic adinoles by recrystallization, for it has been shown that this texture is of a later date than the adinolization [1, pp. 323–6]. Whether the boron was derived from a granitic source, as is favoured here, or was directly associated with the adinolization and derived from the albite-dolerite, it has 'reacted' with some mineral and we must investigate what this may have been.

In the adinole, the chemical composition would suggest a chlorite rich in the amesite molecule, but in the adinoles without dravite, the chlorite that occurs is a diabantite and so removal of iron should have taken place. In other cases, the dravite may replace albite itself, thus necessitating the introduction of magnesia, as would also be the case if the tourmaline molecule had been introduced as such, a possibility which must be borne in mind.

In the dravite-rocks, replacement of a different rock type is probable. The magnesium may represent some dolomitic constituent of a limestone corresponding to the calcareous bands which are found among the sediments at Dinas Head (1, p. 311), in which case, aluminium must have been introduced in large quantities. On the other hand, the sericite so abundant in the rocks which are regarded as representing the initial stages of the alteration to the almost monomineralic dravite rocks, as well as the very fine grain-size and chemical considerations, increase the likelihood that the original rock was an argillaceous sediment poor in iron and rich in magnesia. An argillaceous rock with such a high content of magnesium is admittedly an uncommon type, but there is no evidence for the alternative hypothesis, an introduction of magnesium such as has occurred in the Darling Range granite.

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Observations on the alteration products of stibnite.

By W. R. Schoeller, Ph.D.

[Read June 5, 1941.]

IN the mineralogical literature, stibnite is usually stated to change by oxidation into kermesite and finally into valentinite or senarmontite. Another alteration product is described as antimony ochre, a term loosely applied to several minerals, viz. cervantite, stibiconite, and volgerite (Dana, System of mineralogy, 6th edit., 1892, p. 203).

In my metallurgical experience with stibnite ores, I have never met with kermesite or valentinite. Whenever I have encountered altered stibnite in ores from widely separated localities, it showed a yellowish to buff coating which I took to be cervantite. After spending two years in central China where I examined hundreds of tons of stibnite ores from Hunan province,[1] I had to purchase a specimen of kermesite from a mineral dealer in order to become acquainted with the mineral. The locality of the specimen was given as Bräunsdorf, Saxony.

I have a fine specimen, weighing 4 lb., of more or less completely oxidized stibnite from Shi-kuang-shan, Sinhoa district, Hunan. It is an aggregate of coarse radiating prismatic crystals, the largest of which measures 18 cm. in length. The crystals have the typical morphological appearance of stibnite, but are pseudomorphous; a few fractured crystals exhibit a thin core of unaltered sulphide. The superficial colour of the crystals is buff, but here and there a fracture reveals paler inner layers, greyish-white to cream-coloured.

In an endeavour to identify the oxide mineral, I removed one of the smaller crystals, seemingly free from stibnite. It gave specific gravity 4·160 and hardness 4½–5. In the closed tube much water was given off and a minute red sublimate was formed, the latter proving the presence of a very subordinate amount of sulphide. The powder was insoluble

[1] W. R. Schoeller, Notes on Chinese antimony ores, crude and regulus. Journ. Soc. Chem. Industry, London, 1913, vol. 32, pp. 260–262. Oxygen and metallic antimony in crude antimony. Ibid., 1914, vol. 33, pp. 169–170. In the liquated sulphide produced in Hunan, sulphur was found to be too low for Sb_2S_3, and oxygen was determined by fusing the material in a current of dry H_2S and weighing the water formed.

in hot hydrochloric acid, but soluble on addition of stannous chloride; heated with hydrochloric acid and potassium iodide, it liberated considerable iodine. Hence the specimen is not cervantite (which is anhydrous), nor valentinite or senarmontite (which are soluble in acid).

For the antimony determination 0·2 g. of the finely powdered mineral was boiled in a 300-ml. flask with 3 g. $KHSO_4$, 12 ml. of strong H_2SO_4, and 0·25 g. of tartaric acid until the mass was quite colourless, leaving a little silica. About one hour's boiling was required. After cooling, 50 ml. of water and 12 ml. of strong HCl were added. The flask was gently heated until solution was complete. When quite cold, 60 ml. of cold water was added, and the solution titrated with $KMnO_4$ solution (1·75 g. $KMnO_4$ in 1000 ml.) standardized against sodium oxalate.

Chemical analysis gave: Sb 70·54, H_2O 4·50, SiO_2 1·94, Fe_2O_3 0·16, S 0·16 %. If the sulphur is calculated to Sb_2S_3 and the balance of the antimony to Sb_2O_5, the analysis sums up to approximately 100 %:

Sb_2O_5	93·17 ÷ 323·52,	molecular ratio 0·288
H_2O	4·50 ÷ 18·016,	,, ,, 0·25
Sb_2S_3	0·57	
SiO_2	1·94	
Fe_2O_3	0·16	
	100·34	Sp. gr. 4·160.

The molecular ratios approximate to a mineral of the composition $Sb_2O_5.H_2O$, whereas Dana (loc. cit.) gives the following data for the 'ochres':

Cervantite, Sb_2O_4, sp. gr. 4·084.
Stibiconite, probably $Sb_2O_4.H_2O$, sp. gr. 5·1–5·28.
Volgerite, perhaps, $Sb_2O_5.4H_2O$.
'White antimony ochre', $Sb_2O_5.5H_2O$.

Hence the mineral from Shi-kuang-shan does not correspond to any of the 'ochres' listed by Dana. These minerals appear to be ill-defined.

The information on cervantite given in Dana is rather unsatisfactory: no crystallographic data and no chemical analyses are given. The mineral is stated to be soluble in hydrochloric acid, whereas Sb_2O_4 is substantially insoluble. The specific gravity seems very low compared with that of the hydrous mineral stibiconite and the sesquioxides senarmontite 5·22–5·30, and valentinite 5·566). Dana gives a long list of localities for cervantite, including four British ones; I am wondering

whether the minerals from these localities have been proved to be cervantite by chemical analysis; otherwise I cannot help thinking that some at least of these occurrences of 'cervantite' are in reality hydrous alteration products of stibnite.

The specimen from Shi-kuang-shan described in this communication has been presented to the British Museum of Natural History. Another specimen of native antimony oxide has been presented to the museum by Mr. E. W. Leighton. It is a water-worn pebble weighing 21 lb., representative of several hundred tons of antimony ore found stored in a warehouse in Kowloon old city near Hong Kong, and shipped to England. The exact locality of this ore is unknown, but it was undoubtedly brought down the Si-kiang river via Canton, hence it originated from Kwangsi province. This most unusual shipment of alluvial antimony ore consisted entirely of very hard, brown, smooth rounded pebbles, weighing from over 30 lb. down to a few ounces. Mr. Leighton kindly sent me a few of the smaller pebbles, one of which I broke and partly crushed. The powder was found to contain 4·46 % of water by direct determination, hence the antimony mineral is not cervantite. I hardly think that a more complete chemical analysis of this obviously impure mineral would lead to its identification; the average antimony content of the shipment was in the neighbourhood of 55 %.

At Dr. W. R. Schoeller's suggestion work is now proceeding in the Department of Mineralogy, British Museum, on both specimens referred to in his paper and also a stibiconite from Sonora, Mexico, and artificial preparations of antimonic acid. X-ray powder photographs of the altered stibnite from Shi-kuang-shan, the Kwangsi pebble ore, and stibiconite from Sonora, Mexico, are identical.

Native gold and silver with other minerals from the Old West mine, Penhalonga, Southern Rhodesia.[1]

(With Plate III.)

By A. M. Macgregor, M.A., F.G.S.

Geological Survey of Southern Rhodesia.

[Read June 5, 1941.]

LARGE specimens of native gold showing crystalline form are not at all common in Southern Rhodesia, but the recently discovered gold with adherent silver from the Old West mine, Penhalonga, would be outstanding wherever it had been found.

About the middle of December 1940, Mr. D. V. Burnett, Director and Consulting Engineer to the Rezende Mines Limited, the owners of the property, lent two specimens to the Geological Survey for examination. The following week Mr. B. Lightfoot, Director of the Southern Rhodesia Geological Survey, visited the mine and examined the cavity where the specimens had been found. He made notes and collected specimens of the associated minerals, and borrowed a few other specimens which had been retained at the mine.

In a description of the Rezende Old West mine Mr. A. E. Phaup[2] explains that the ore-body is a sheet of quartz-porphyry averaging 20 feet in thickness, dipping at an average angle of 30° to the south, and intruding into a boss of quartz-diorite. The quartz-porphyry has been shattered and riddled with stringers of vein quartz containing pyrite, galena, a little chalcopyrite, pyrrhotine, and gold. The gold in the ore is confined to the mineralized quartz stringers which assay about an ounce to the ton, but the quartz-porphyry body as a whole is treated as low-grade ore, and is worked to yield a recovery of approximately 2 dwt. per ton. The mineralization has not been even and tends to be greatest near one or other of the walls. The ore-body is cut by strike faults which dip vertically and throw the reef down on the southern side. The vug in which the specimens were found adjoined one of these faults, being inclined upward into the down-faulted hanging-wall country-rock on the south side of the fault.

[1] By permission of the Director, Geological Survey of Southern Rhodesia.

[2] A. E. Phaup, The geology of the Umtali gold belt. Bull. Geol. Surv. Southern Rhodesia, 1937, no. 32, pp. 132–134. [M.A. 7-432.]

The position of the vug is shown in the attached plan and section (figs. 1 and 2), and is explained in the following description by Mr. Lightfoot: 'The vug was found in no. 6/2 E. stope drive, 42 feet above the 6th level at a vertical depth of 490 feet below the collar of no. 2 shaft. A fault forms the southern wall of the stope drive and of the box-

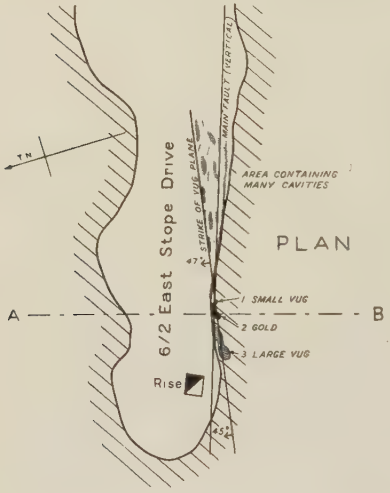


FIG. 1.

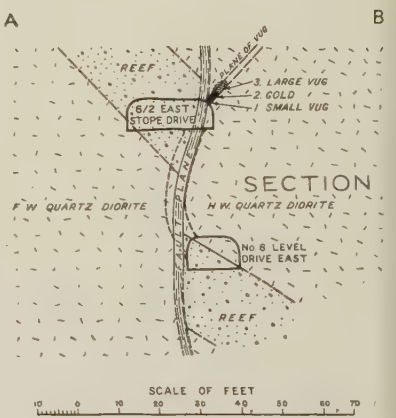


FIG. 2.

Figs. 1 and 2. Plan and section of 6/2 East stope drive, Old West mine, Penhalonga, Southern Rhodesia.

hole connecting it with the main drive below. A series of vugs carrying quartz and calcite had previously been noticed along this fault plane, particularly at the junction of another fault which meets at a small angle. On December 10, 1940, after a blast, a boss-boy was barring down bits of loose hanging wall to make the stope safe for the on-coming shift, when he brought down one piece which opened up a cavity in a corner of the roof in which shining leaves of gold could be seen. He went to fetch the shift boss, Mr. T. Lines, who could scarcely believe his eyes. Here were the biggest pieces of visible gold he had ever seen in his life, three shining sheets of gold, about a quarter of an inch apart, sandwiched between white glistening crystals of calcite. Mr. Lines set to work with a chisel. It then became obvious that this was no ordinary gold, but was ornamented with triangular markings each with a black spot embossed upon it. Two selected specimens were sent to Mr. D. V. Burnett at the head office in Salisbury, and the remainder was smelted

down. 33 oz. of gold plates gave 33 oz. of bullion containing 789·7 parts of gold and 180·0 parts of silver per thousand.'

So far as is known only five plates of gold, including the two which were sent to Mr. Burnett, escaped the holocaust; but a few specks of crystalline gold were found among other minerals in the specimens collected by Mr. Lightfoot. The largest specimen is the plate of which photographs of the two sides are shown in plate III. It measures roughly 9×10 centimetres and averages 0·44 millimetre thick. Mr. E. Golding estimates that the weight of gold is 41·1 grams (1·32 oz. Troy). Part of the plate is enclosed in a crystal of clear calcite. The second specimen is smaller, and consists of gold associated with galena partly embedded in a gangue of calcite, quartz, and laumontite. The remaining three specimens are plates with maximum dimensions of 4×3, 5×2, and 2×2 centimetres respectively. The gold is of rather pale colour. It is mostly bright, but in places it is stained with an iridescent tarnish.

As may be seen in the photograph (pl. III), the large surfaces of the sheet are broken by small projecting pyramids rising in steps or terraces with sloping edges on equilateral triangular bases. Many of these pyramids are surmounted by dark grey nodules or studs, which are found on examination to be native silver. A small crystal was detached and measured on a goniometer. The faces unfortunately are not very smooth and give indifferent reflections, particularly as the crystals are all somewhat bent. Three zones were measured. As might be expected the large surfaces belong to the octahedron. The angle read between this and the terrace slope faces averaged 29° 27′ for four readings, which is sufficiently near to 29° 30′, the theoretical value, to leave little doubt that the terrace slopes belong to the four-sided trisoctahedron (icositetrahedron) (311). There is no evidence of the presence of cube faces, nor of the rhombic-dodecahedron, but reflections were observed indicating the presence of forms (221) and (811). A conventional drawing of these forms is shown in fig. 3.

The smaller specimen, measuring 5×2 cm., is one of exceptional beauty. It is very similar to the large specimen except that some of the pyramids are surmounted by beautifully faceted little crystals on short stalks. One of these, about 1 mm. diameter, has the form shown in fig. 4. It consists of the octahedron and the form (311) which has been reduced to small crosses about the cubic axis by a form which may be described as a four-faced dodecahedron (hexakisoctahedron). Dana[1]

[1] E. S. Dana, Amer. Journ. Sci., 1886, ser. 3, vol. 32, p. 137, fig. 6; System of Mineralogy, 6th edit., 1892, p. 14, fig. 5.

figures a very similar crystal from California, in which he indexes the faces between the angles of the crosses as x (18.10.1).[1] In the Penhalonga specimen the faces are too dull to be measured, but the plane angles on the octahedron faces indicate that the form must be near to (951). Twins are visible in some of the small crystals.

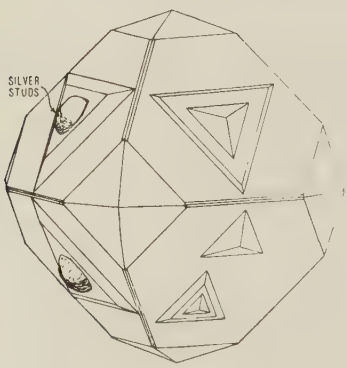


Fig. 3.

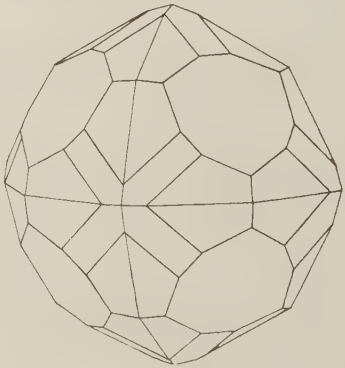


Fig. 4.

Fig. 3. Conventional sketch to show crystal form of gold with adhering silver.
Fig. 4. Crystal of gold from Old West mine, Penhalonga, Southern Rhodesia.

In the photographs (pl. III) the effects of twinning may be seen in places where the triangular pyramids are oriented 180° from those in the main part of the specimen.

The bending of the crystals was probably caused by movements of the walls of the vug. Mr. Lightfoot was able to collect a specimen of calcite preserving a mould of the curved gold surface of a large specimen with casts of the triangular ornamentation clearly preserved.

In contrast with the gold, the native silver is rarely distinctly crystalline. It is usually rounded and often occurs as nearly perfect hemispheres (fig. 5). The surface is tarnished to a dark lead-grey, and is always dull. Crystal faces can be seen on some of the studs and a few have definite modified triangular outlines, orientated approximately parallel to the sides of the gold pedestals on which they stand. The triangle sides are convex and are due to a combination of two four-sided trisoctahedral (icositetrahedral) forms. That this mineral is chemically silver was determined on three of the studs from two specimens. It is soft and malleable, but harder than the gold and it does not bend as readily. Some of the studs are broken with irregular fractures when the

[1] The indices (18.10.1) cannot be correct with (311) lying in the zone [(*hkl*)(*hlk*)] as shown in the drawing.

supporting gold has been severely bent. In other places the silver studs have wholly or partly broken free from the gold, leaving hollow scars nearly as deep as the projection of the silver above the gold surface.

FIG. 5. Photomicrographs by reflected light of hemispherical studs of native lver on crystalline gold from Old West mine, Penhalonga, Southern Rhodesia. 30.

his is interesting, as it shows that the gold and silver were deposited ultaneously, and were incompletely isomorphous under the condi- us of temperature and pressure reigning at the time of deposition.

The assay values quoted above show that the bullion produced from the vug contained 78·97 % of gold and 18·0 % of silver, some of which must have been in the native state. To ascertain the purity of the gold crystals, some small pieces weighing about half a gram in all were carefully scraped free of all adhering silver with a dentist's tool, and assayed by the Government Metallurgist. Separate portions gave Au 80·615, Ag 18·463, and Au 81·093, Ag 18·193%. These figures are rather surprisingly similar to those of the bullion. Unfortunately it has not been possible to collect sufficient of the silver to determine how much gold is contained in it. The Mining Commissioner's returns show that the ratio of gold and silver produced by the mine is 65·8: 34·2.

Other minerals associated with the gold and silver in the vug include galena, pyrite, quartz, calcite, laumontite, and chlorite. The larger vugs in which no gold was found are lined with the same minerals with the exception so far as is known of galena.

Galena occurs in contact with the gold in several small specimens. It shows only as cleavage masses and no external form has been observed.

Pyrite does not seem to occur in contact with the gold in any specimen, although small crystals may be found entirely embedded in the associated calcite. It is abundant in the altered country-rock. In the larger vugs small pyrite crystals are very numerous, and are among the last to form, occurring frequently on the outer surface of the laumontite.

Quartz crystals are generally singly terminated prisms, and water-clear. They were the earliest crystals to form on the walls of the vugs.

Calcite usually shows the form of a somewhat obtuse rhombohedron combined with the base. All the faces are rough, the base being particularly mottled. The rhombohedral faces are striated parallel to their intersections with the base. They tend to have a convex cylindrical curvature with axes parallel to the striae. Cleavage fractures truncate the edges radiating from the corners of the base. Contact-goniometer readings suggest several forms are present between (331) to (221). There is frequently a sharp change in colour in the crystals from bluish-white in the older parts to pale yellow in the later formed portions, but all effervesce freely with cold dilute hydrochloric acid.

Chlorite as minute crystals of vermicular form is present in some gold-bearing specimens, and forms an abundant deposit as a greyish-green powder in the interior of the large vugs. Small crystals of the same mineral are also enclosed in the outer parts of clear crystals of quartz. The powder is composed of isolated, sensibly hexagonal prisms elongated

perpendicular to a perfect basal cleavage, and usually curved into a U or spiral. The refractive indices are α 1·607, γ 1·611, $\gamma - \alpha$ 0·004. No optic axial figure could be recognized in the very thin lamellae, but viewed laterally they show negative elongation. The mineral is therefore optically positive. The pleochroism is strong, $\alpha = \beta$, dark sage-green, γ pale yellow. Specific gravity is 2·90, varying slightly. The optical properties and crystal form agree with prochlorite as defined by Winchell.[1] A chemical analysis by Mr. E. Golding of the powder washed free from lighter constituents in bromoform is given below. The composition works out as amesite 32, antigorite 29, daphnite 21, ferroantigorite 18, with a small excess of silica.

SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	MgO.	H_2O+.	H_2O-.	Total.
27·55	19·74	0·66	20·68	0·23	18·42	11·39	0·31	98·98

Also traces of Na_2O, K_2O; absence of TiO_2, CaO, CO_2.

Laumontite is the last mineral to form. It is generally soft and fibrous, and usually forms a mat separated from the surface of the main mass of rock by an air space a few millimetres deep. It appears to have crystallized near the top of standing, or gently flowing, water. The same mineral occurs in joint faces in the rock and in the gold-bearing specimens. The common shape is a prism (110) with angles near 90°, terminated obliquely by a single face, perhaps ($\bar{2}01$), inclined at about 60° to the prism axis. Silky striations on the faces made measurement of the angle impossible. Under the microscope the most noticeable feature is the high extinction-angle, which reaches 43° from the prism axis. The following characters were determined: α 1·5048, γ 1·5176, $\gamma - \alpha$ 0·0128, $\gamma : c$ 43°; sp. gr. between 2·26 and 2·32. The mineral reacts for CaO, Al_2O_3, SiO_2, and H_2O. It fuses with swelling, and gelatinizes with HCl.

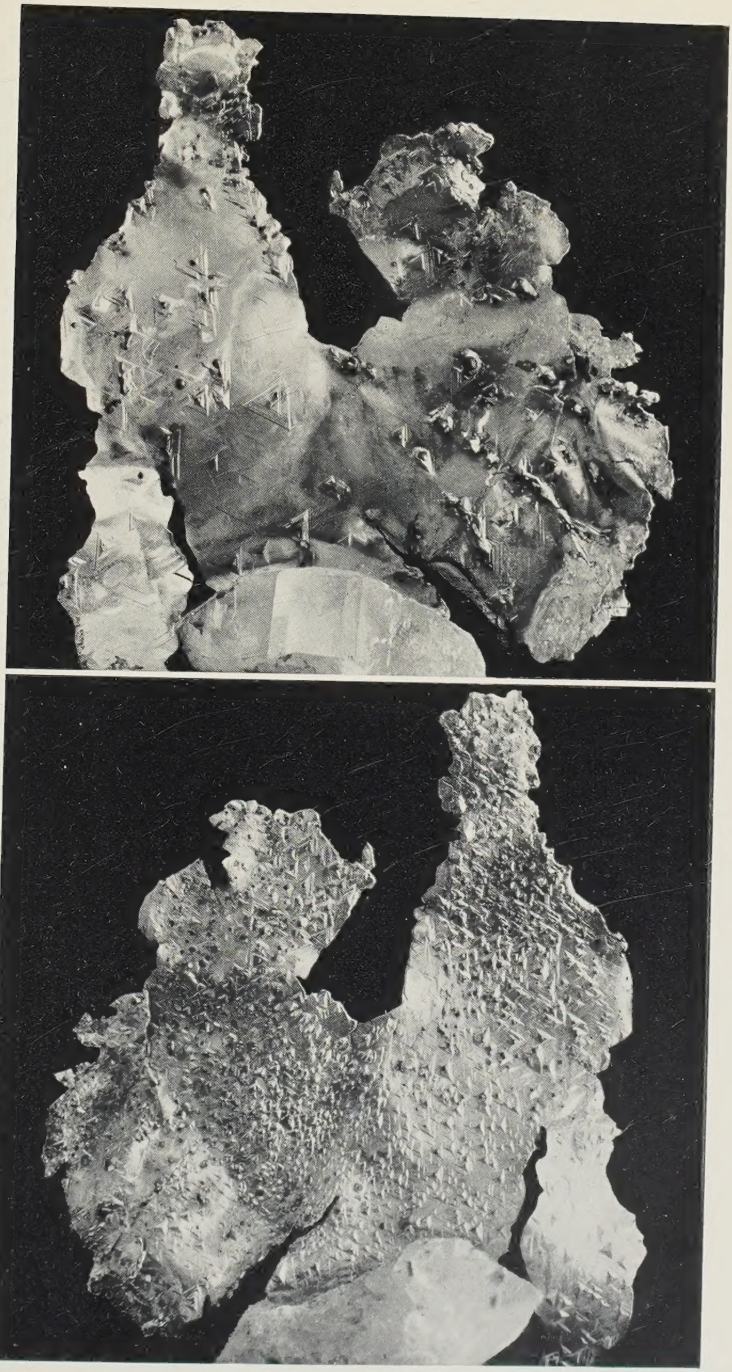
Conclusion.—There can be little doubt that the deposition of this gold is due to a secondary process. The strains which formed the vug were connected with the strike faulting which was subsequent to the emplacement of the auriferous quartz veinlets in the quartz-porphyry. These perhaps resulted from the contraction of the latter during cooling. The presence of pyrrhotine indicates that the temperature at that time was high. The association of the minerals in the vugs, however, suggests a very much lower temperature, which may account for the simultaneous crystallization of gold and silver in contact with each other.

[1] A. N. Winchell, Elements of optical mineralogy, 3rd edit., 1933, pt. 2, p. 276.

It appears probable that the mutual solubility of gold and silver in the crystalline state decreases with fall of temperature.

Explanation of Plate III.

Photographs of the two sides of a sheet of crystallized gold with adhering silver, from Old West mine, Penhalonga, Southern Rhodesia. (Photo. A. M. M.) Slightly reduced.



A. M. Macgregor: Gold from Southern Rhodesia